Importance of ocean-climate conditions on forage species and top-predator distribution patterns off northern-central California

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Objective: Provide information on the distribution and abundance of forage species used by baleen whales to address past and future whale entanglement risks

- Evaluate the potential use of forage species indicators to understand whale distribution patterns
  - They go where the food is
- Review past spatio-temporal fluctuations of forage species
  - Krill abundance variability
    - Predictable hotspots
    - Shelf and oceanic variability
  - Anchovy variability and distribution shifts
  - Species indicators of anomalous ocean conditions
- Ocean conditions and forage species occurrence during 2013-2016

Key Concepts

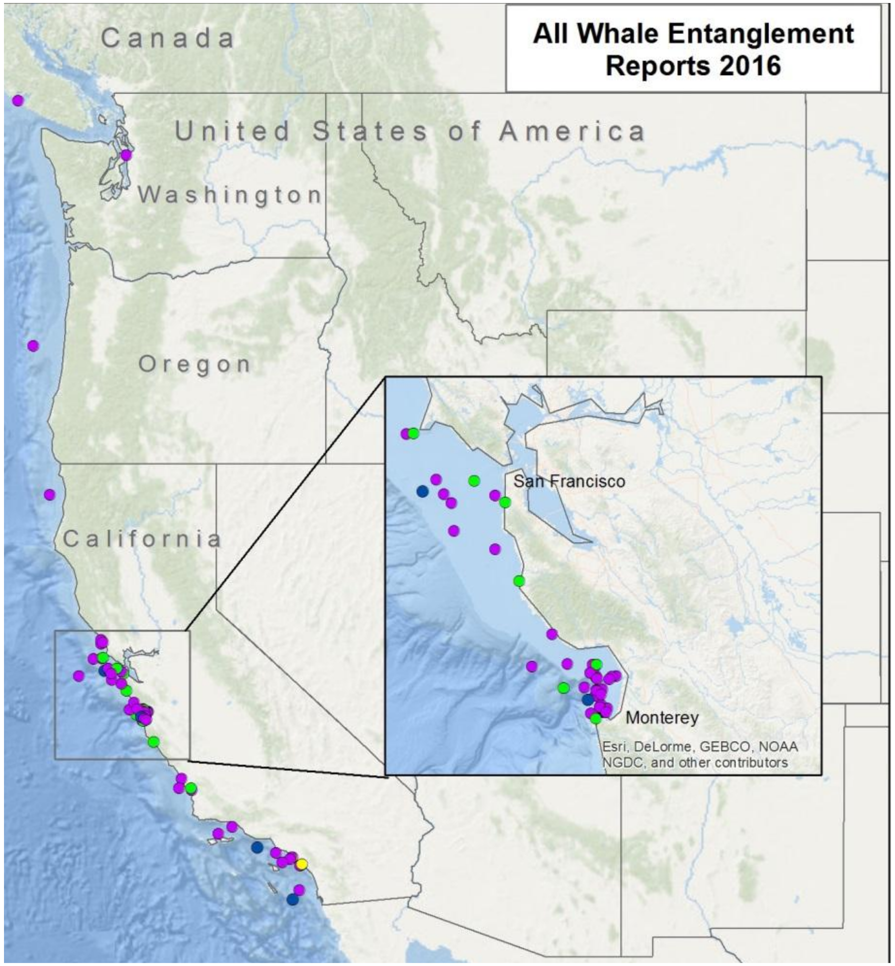
- Relationship between abundance and distribution
  - Abundance vs. patchiness
  - Fundamental aspect of swarming/schooling organisms
    - krill and forage fish population dynamics (world-wide)
  - May reflects 2 basic states (with gradients in between)
    - High abundance, more patches, greater distribution
    - Low abundance, fewer patches, reduced distribution
- Regional distribution shifts
  - Shelf and oceanic habitats
  - Movements from northern and southern California Current regions
  - Thermal habitat refugia
    - submarine canyons

Key Concepts

- Ocean-climate conditions drive abundance and distribution of forage species off central California:
  - High Krill abundance: favor cooler/stronger upwelling years, increased strength of California Current and influx of sub-arctic water
  - Anchovy: favor warm/weaker upwelling years, influx from the southern main spawning region in CA bight
    - Expansion
    - Contraction into coastal environments at low population sizes
- **Prey-switching** is a major foraging behavior utilized by highly mobile predators (seabirds, marine mammals)
  - display striking redistribution patterns in response to the availability of their prey
  - Predators display thresholds responses to prey species abundance and patchiness

Regional Context

- **Why focus on forage species occurrence during May-June?**
  - NOAA-NMFS Rockfish Recruitment and Ecosystem Assessment Survey; 1983-present
  - Winter ocean-climate conditions (e.g., pre-conditioning) drive development of spring and summertime forage species base in shelf and oceanic habitats
  - Highest numbers of recent humpback whale entanglements off central California occurred during late spring through summer
- **What happened to key forage species abundance and distribution during the anomalous ocean-climate event of 2013-2016?**

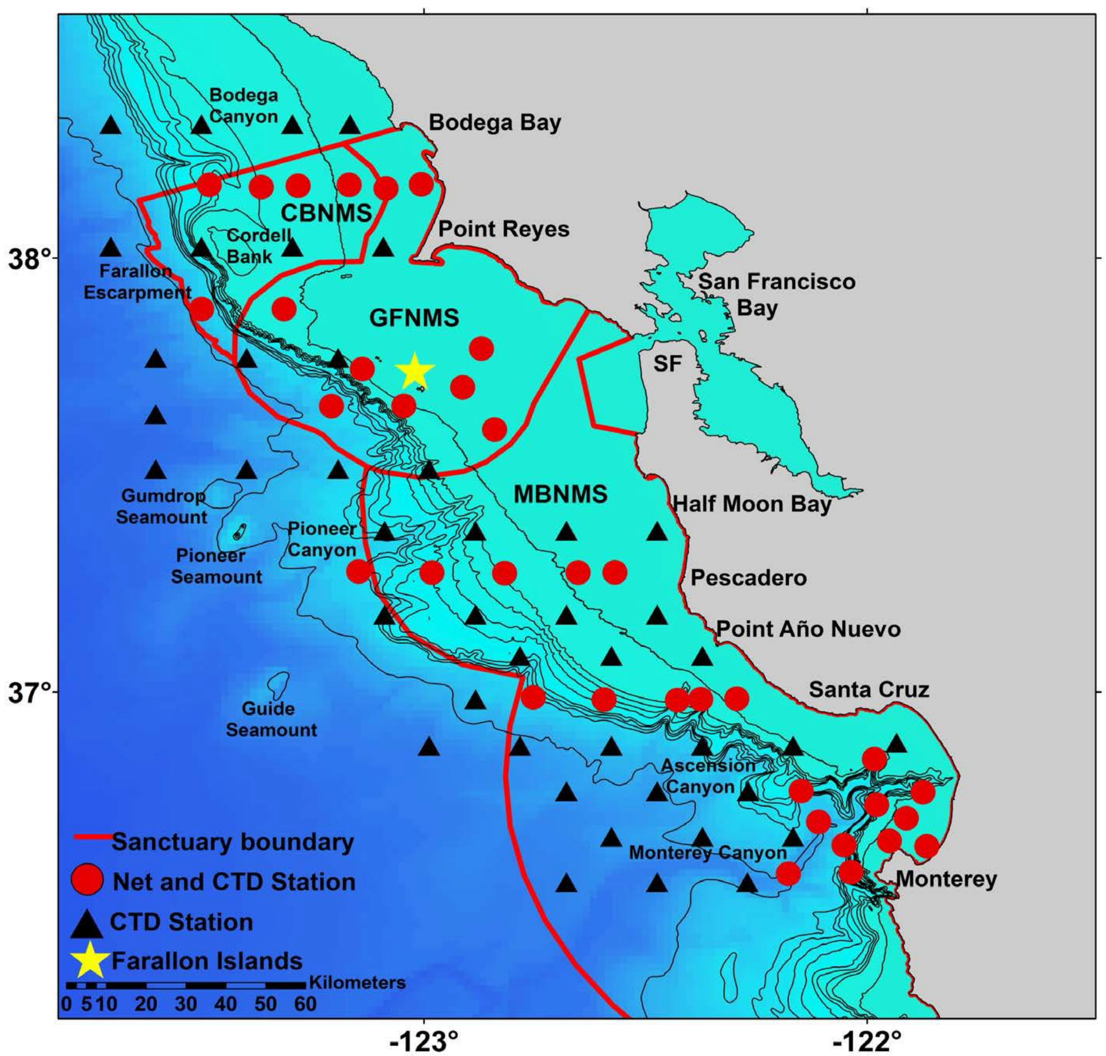


From NOAA WCR Entanglement 2-16 Summary R

Baseline conditions of ocean-climate conditions and forage species distribution and abundance

Rockfish Recruitment and Ecosystem Assessment Survey (RREAS); central California Region

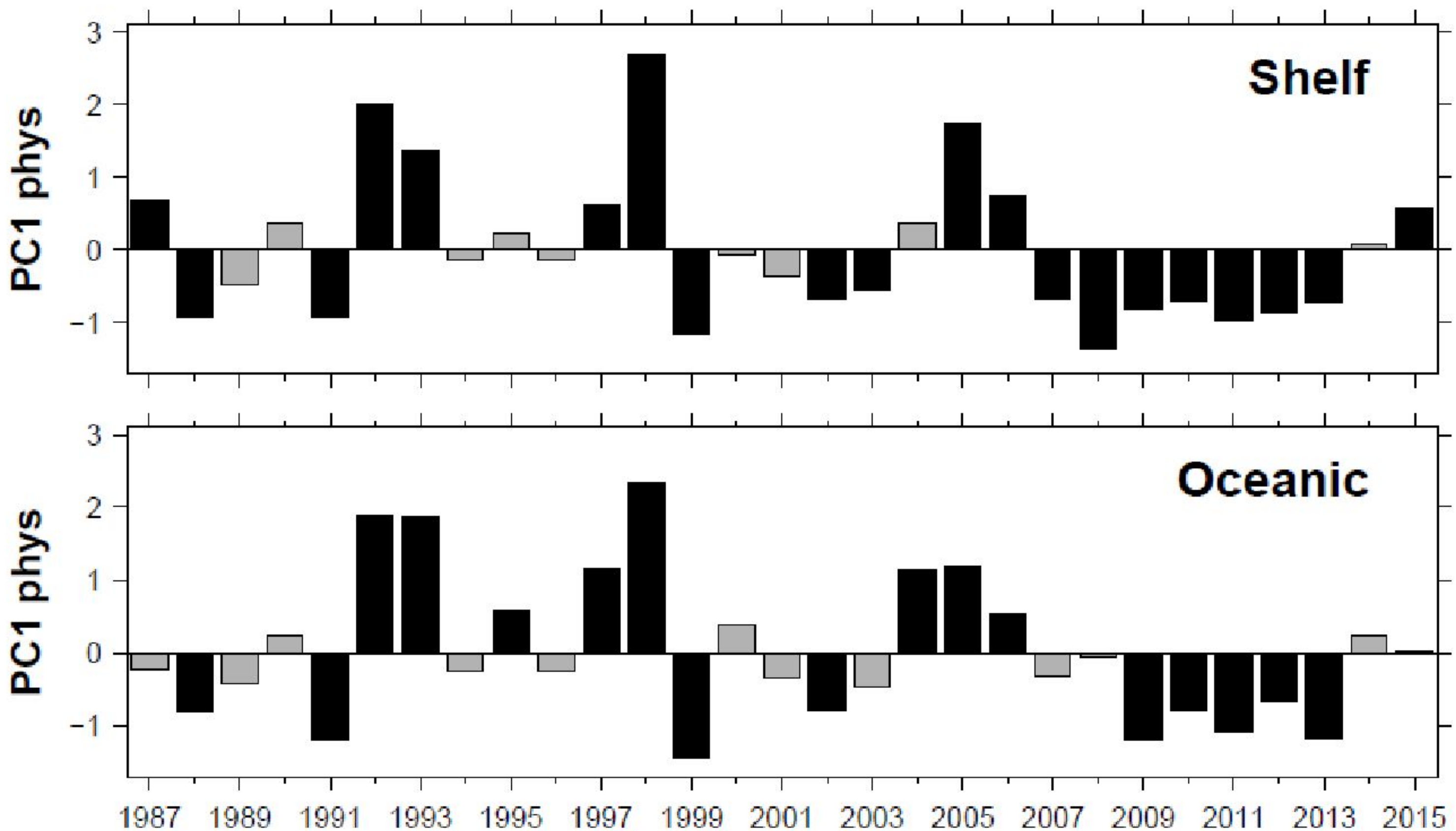
- May-June; 1983-present
- Survey expanded in 2004 to cover entire CA coast
- Net targets 30 m depth; 15-minute haul; hydrographic (CTD) casts
- 35 core stations
- Sampled 2-3 times per survey
- Sub-divisions among Shelf, Oceanic and Monterey Bay sampling areas
- Designed to capture late-larval/early juvenile stages fishes, coastal pelagic species, as well as adult stages of krill (Euphausia), pelagic shrimps (e.g., Seregestidae) and gelatinous zooplankton (e.g., Scyphozoa and Tunicata).



Rockfish Recruitment and Ecosystem Assessment Survey (RREAS); central California Region

Regional indicator of ocean-climate dynamics derived from hydrographic station data

Positive values: Warm, low salinity, increase depth of 26.0 isopycnal; increase in anchovy abundance/occurrence



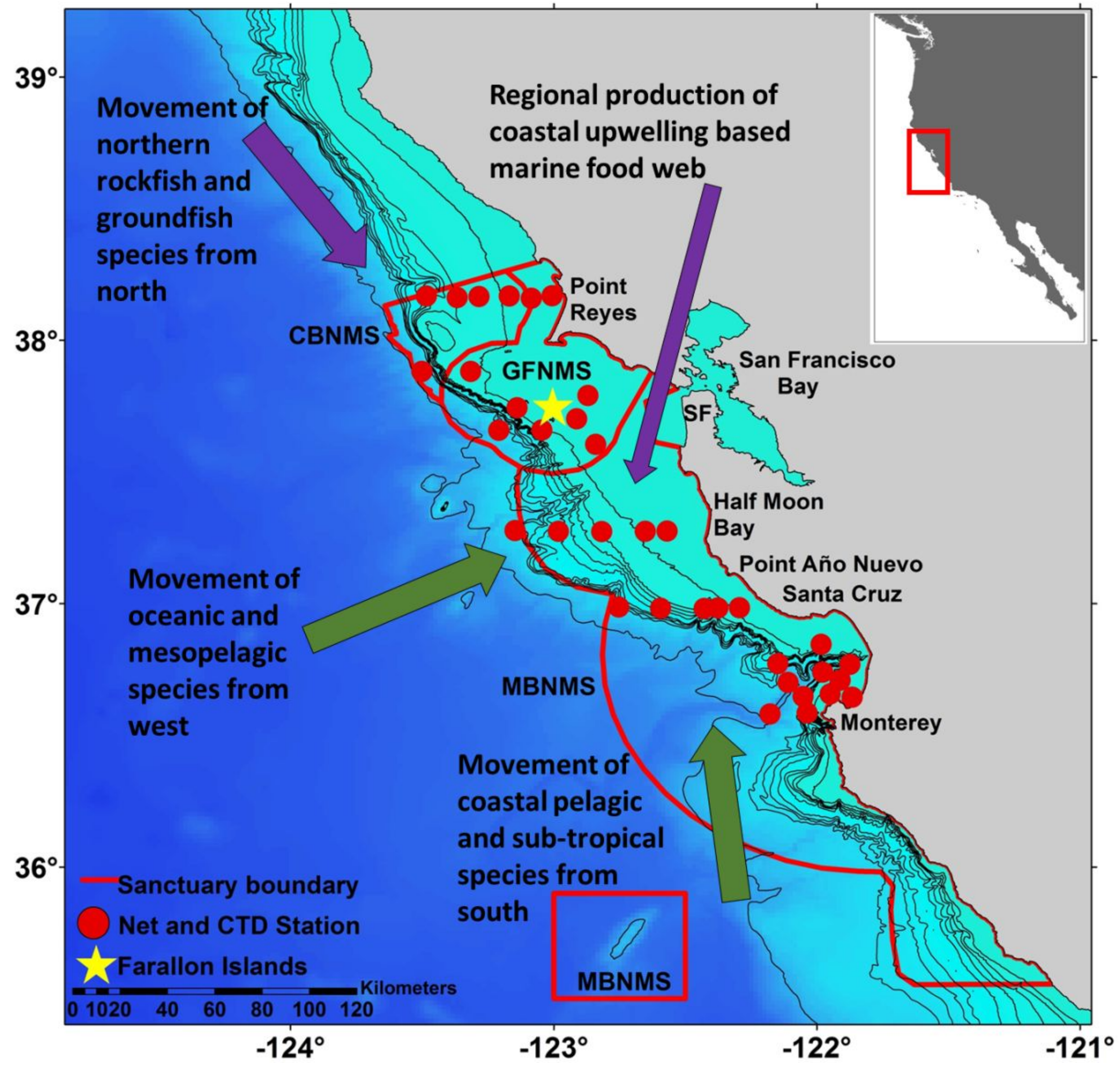
Negative values: Cool, high salinity, decrease depth of 26.0 isopycnal; increase in krill abundance/occurrence

Regional ecosystem oceanography: local production and regional shifts in forage species

Time series analysis of species abundance and diversity indicates two major indicators of variance (1) local/regional production of juvenile groundfish and krill populations and (2) coastal pelagic species (e.g., anchovy, squid), mesopelagic fishes and subtropical species

Arrows indicate generalized directional shifts of epipelagic species into the study region, representing northern, western and southern movement patterns.

National Marine Sanctuaries (NMS): Cordell Bank (CBNMS), Greater Farallones (GFNMS) and Monterey Bay (MBNMS).



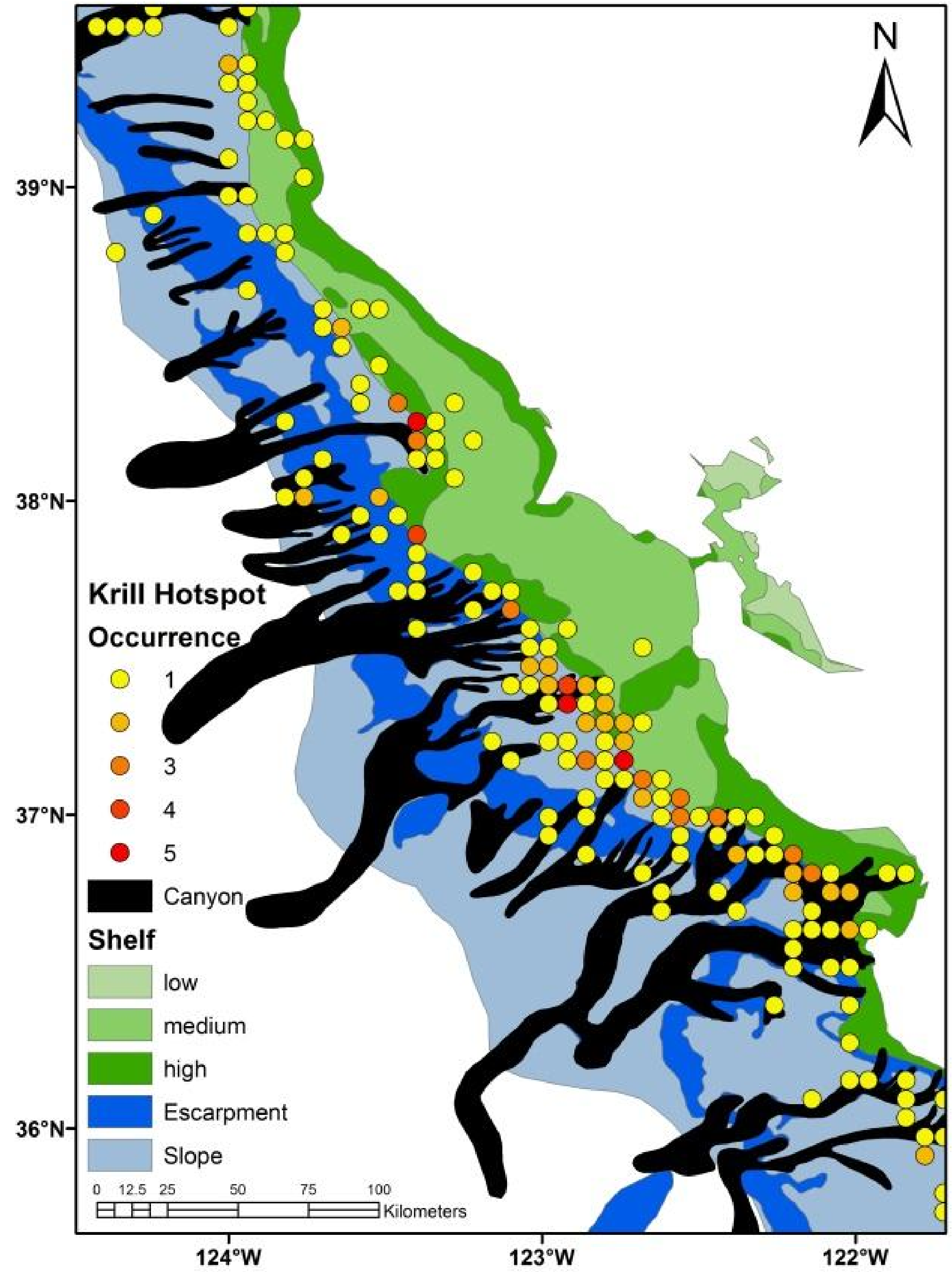
Krill Hotspots

Krill abundance hotpots are strongly associated with the shelf-break and submarine canyon heads. Hotspot intensity varies among years, but krill hotspot locations are predictable and persistent.

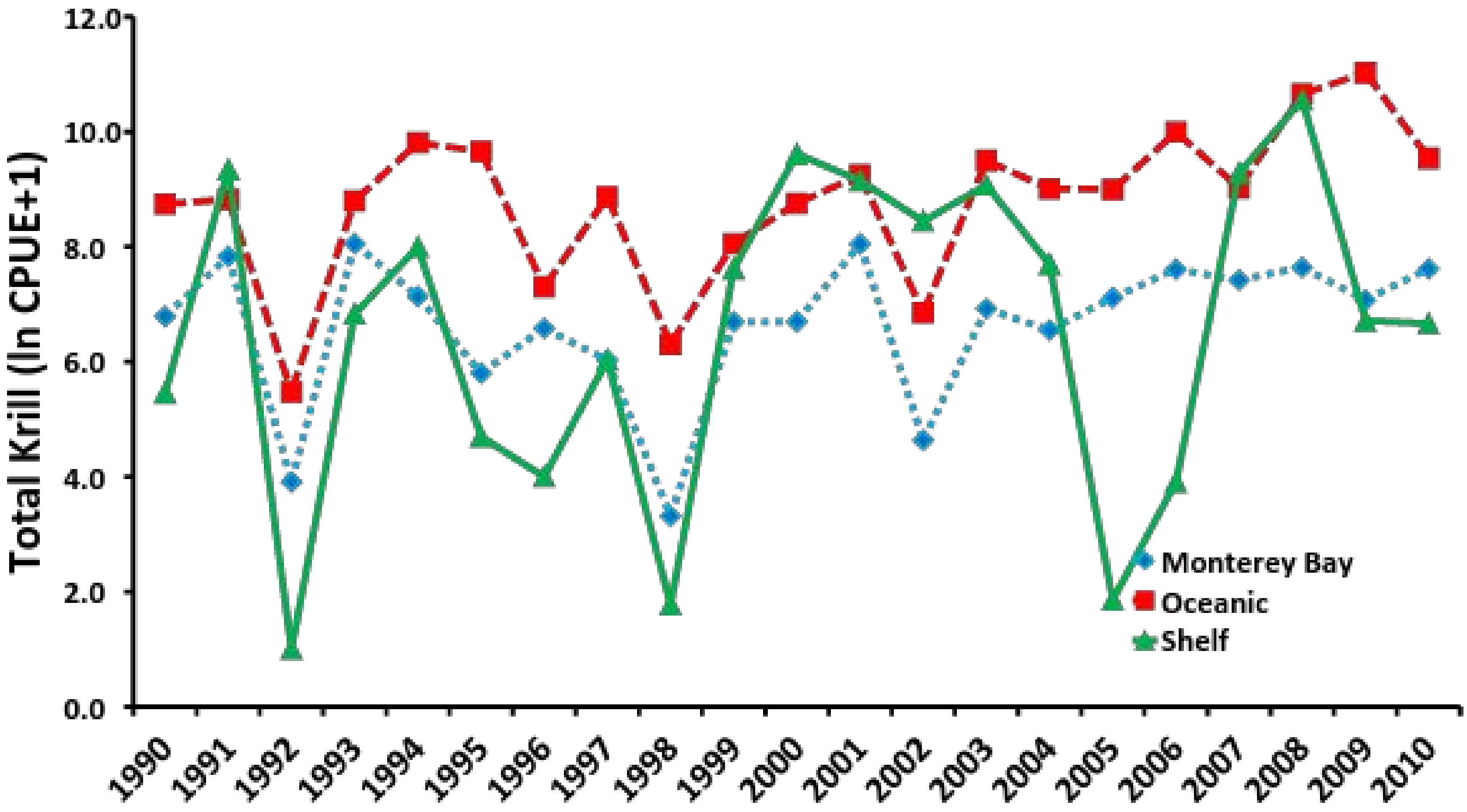
Disassociated from strong upwelling zones.

Predictive models are available.

Data derived from 15 years of hydroacoustic surveys sampled during NOAA-NMFS Rockfish Surveys; 2000-2015 (50K nautical miles sampled).

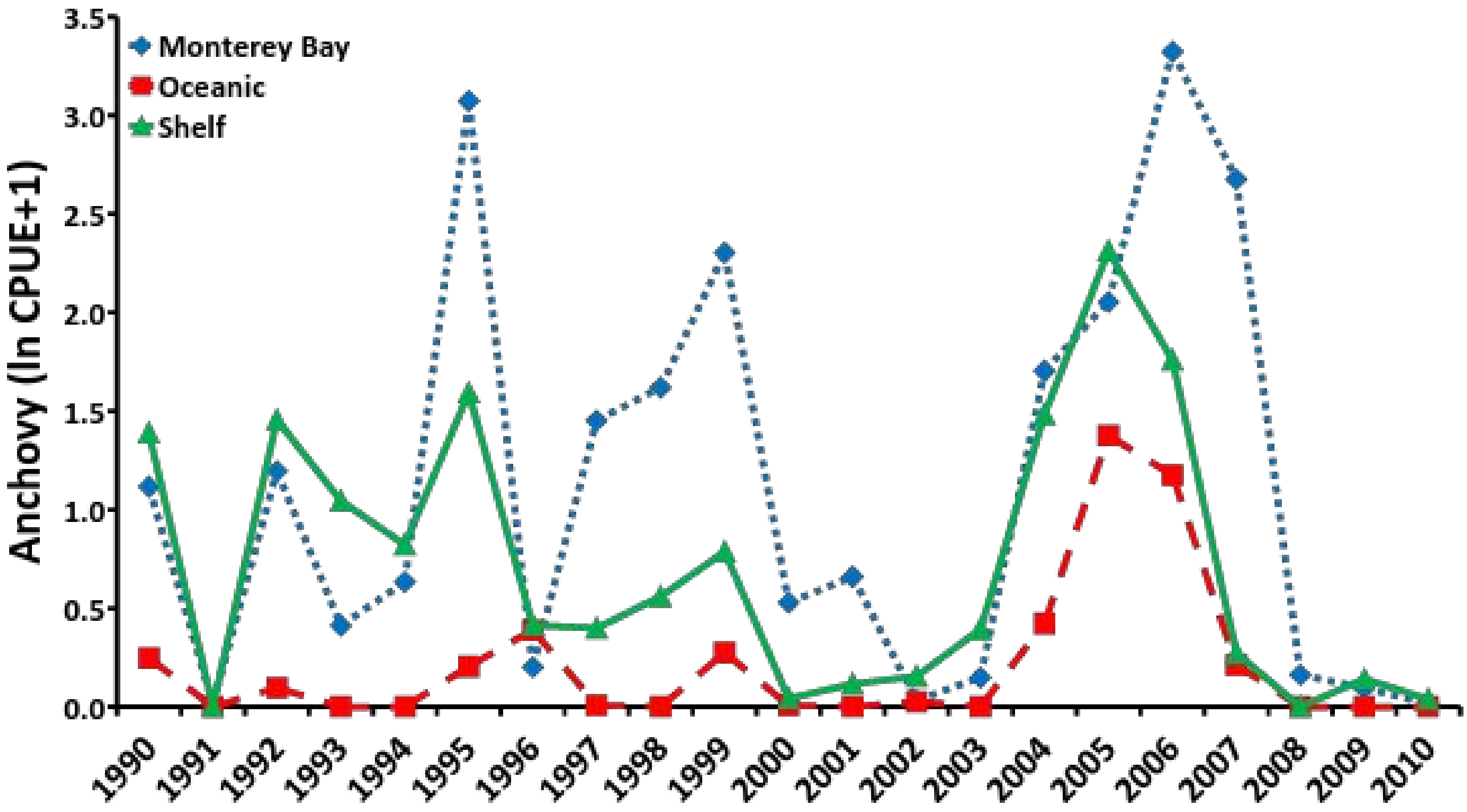


Krill variability (net hauls)



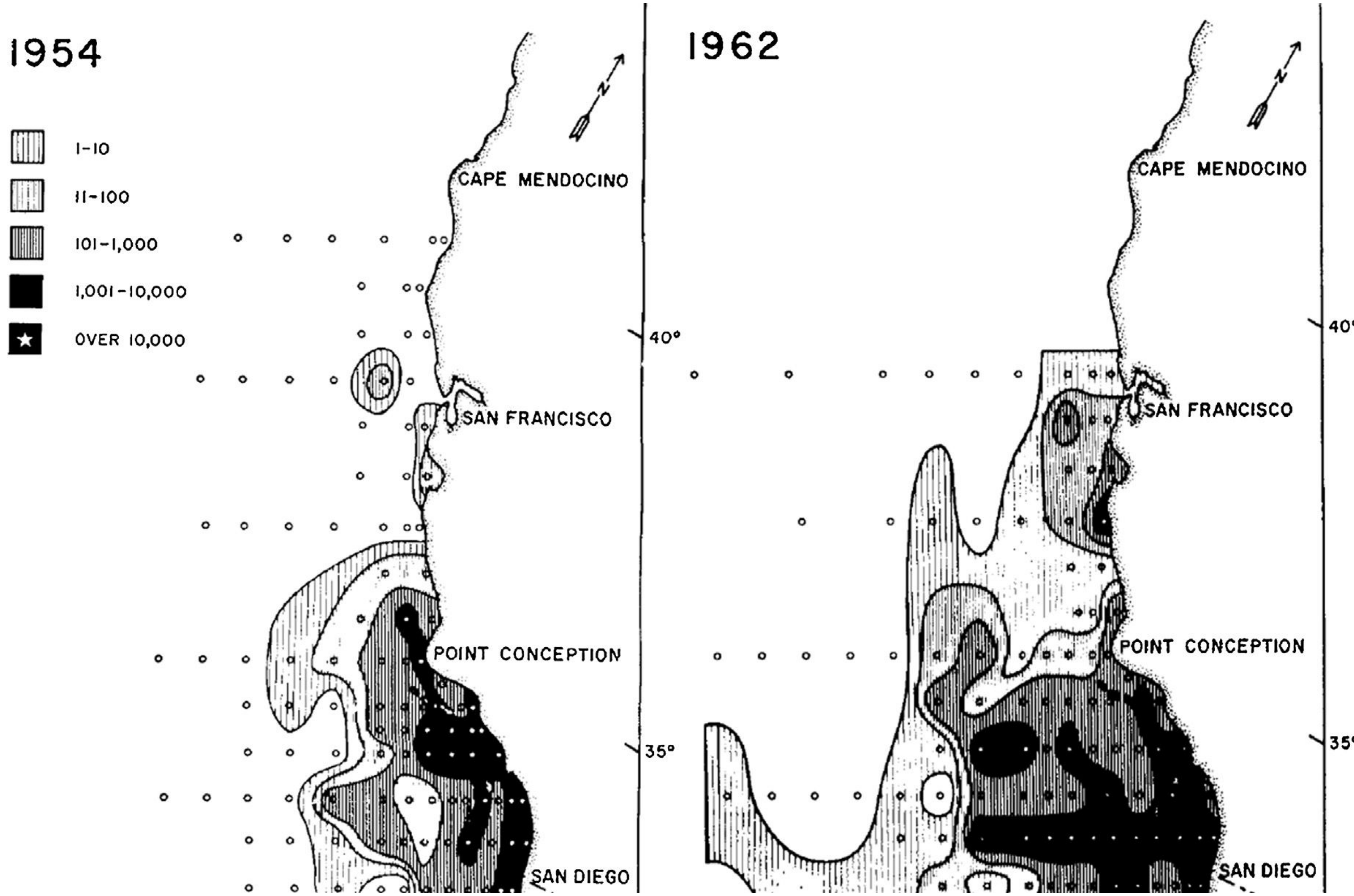
Note: Low frequency variability of shelf krill abundance is linked to variability of winter ocean conditions; declines in warm/weaker upwelling years

Anchovy variability (net hauls)



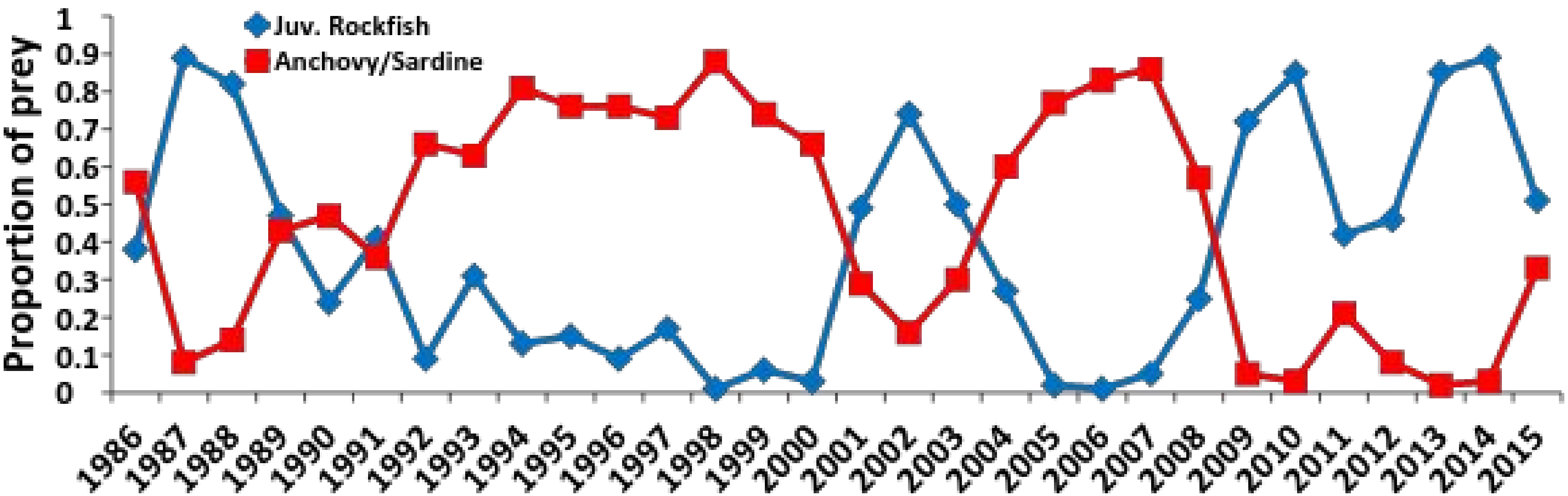
Note: Time series are episodic and variability is linked to warmer ocean conditions

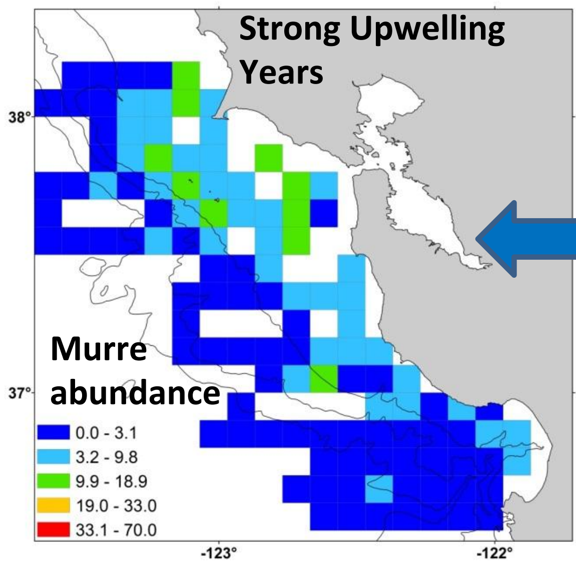
Past shifts in anchovy distribution and abundance



From Kramer and Ahlstrom (1968): Comparison of southern California anchovy larval distributions at low population size (left) and high population size (right) showing areal expansion when the stock is more abundant.

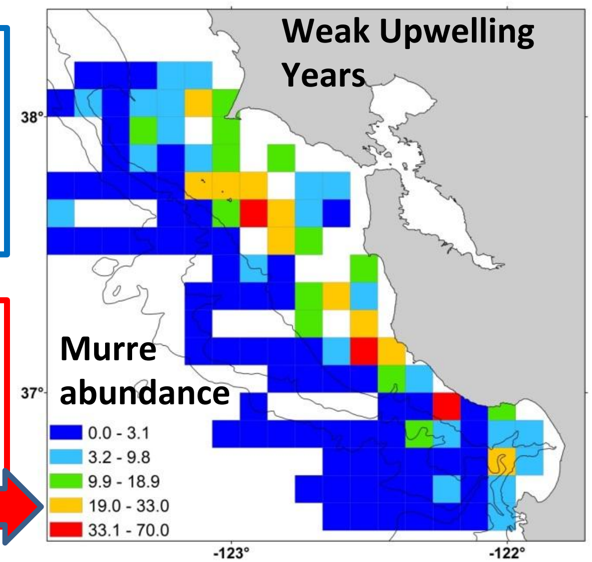
Common Murre diet (Southeast Farallon Island): Prey-switching and foraging distribution shifts





Fewer high density murre aggregations when feeding on juvenile rockfish (co-vary with strong krill years).

More high density murre aggregations when feeding on anchovy (co-vary with low krill years

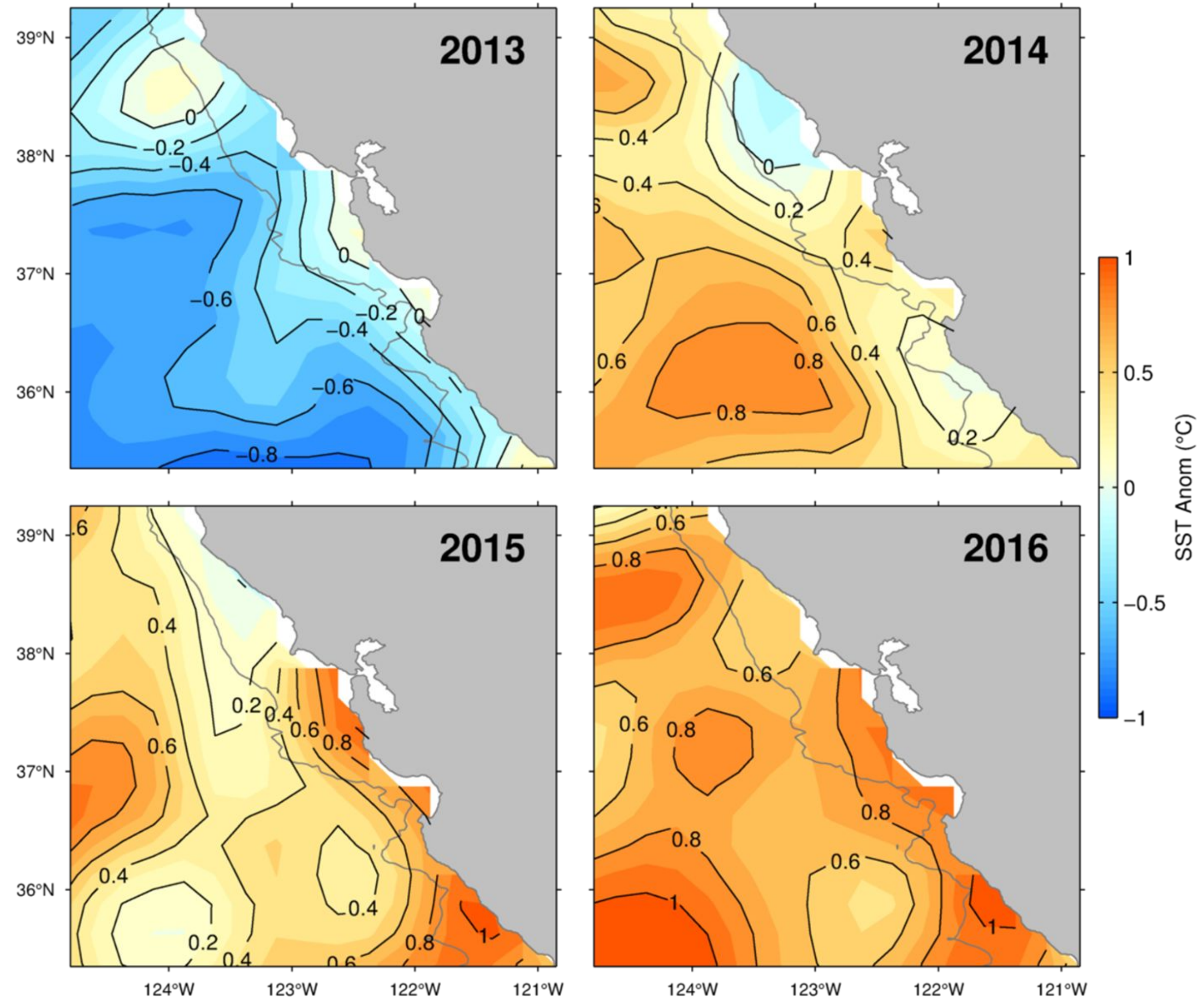


**Diet Data from Point Blue*

Ocean-climate conditions and distribution and abundance of forage species; 2013-2016

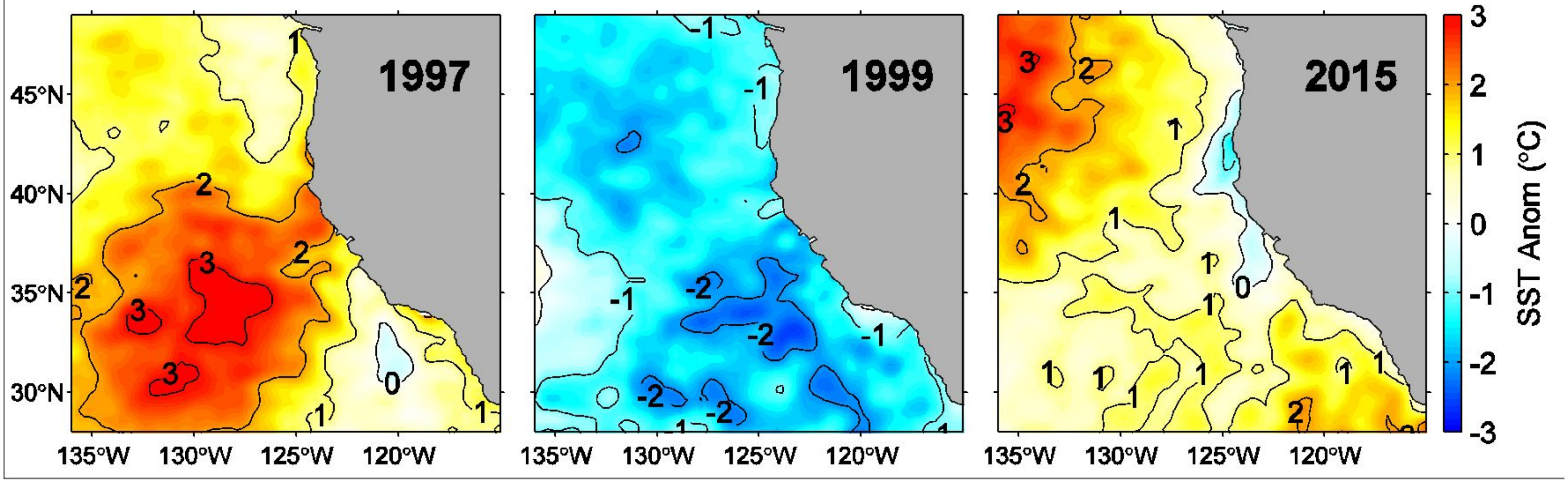
- Objectives:
  - Evaluate ocean temperature conditions
    - Regional and basin scales
    - Relative to past extreme climate events
  - Forage species diversity
  - Acoustic assessment of krill abundance and patchiness
  - Assessment of net-haul catches of krill and anchovy
  - Baleen whale sightings

Satellite sea surface temperature (SST) anomalies derived by subtracting May/June mean for a given year from the long-term May/June mean (1982-2016).

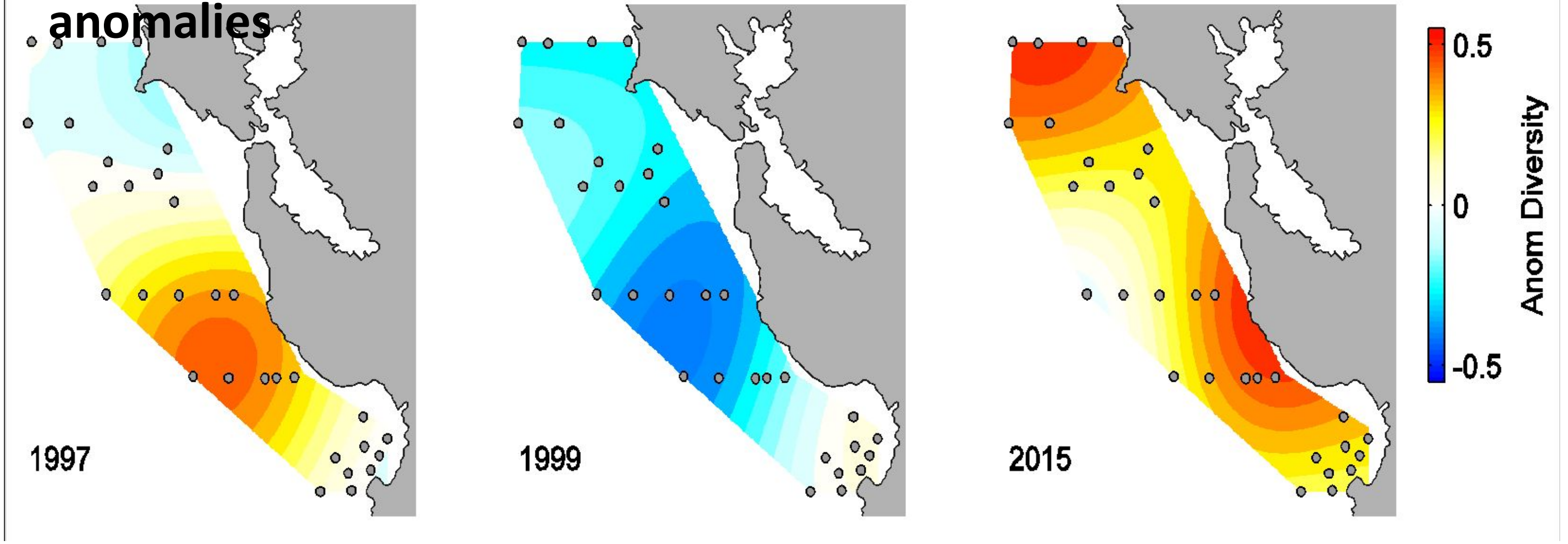


Ocean-climate dynamics and forage species diversity

Satellite sea-surface anomalies: El Niño, La Niña and 2015

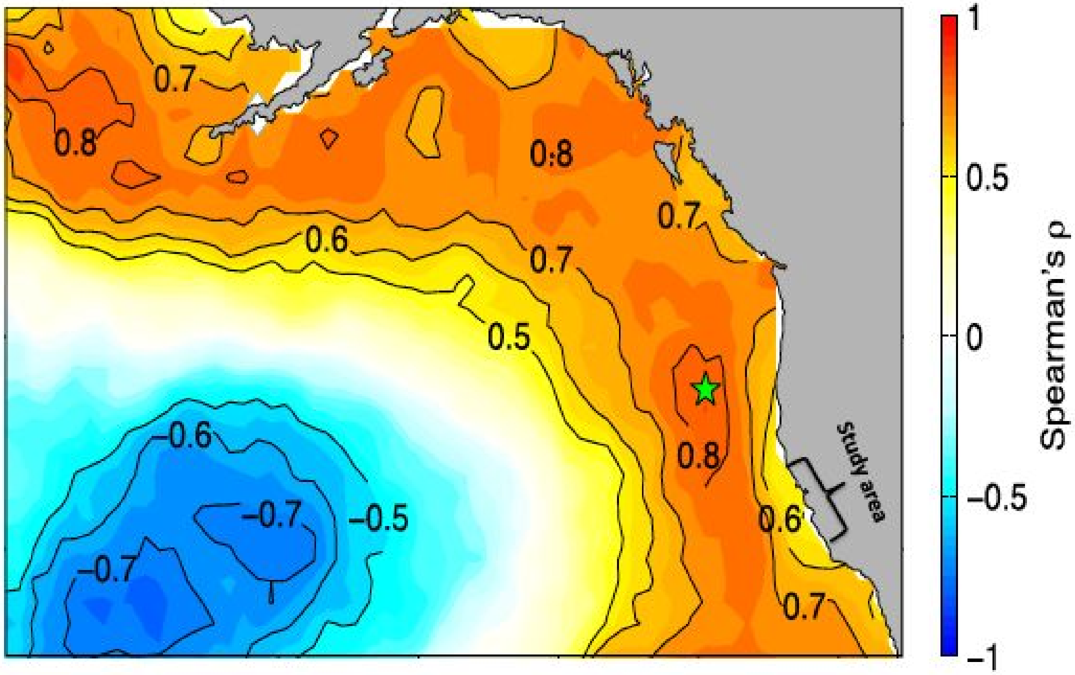


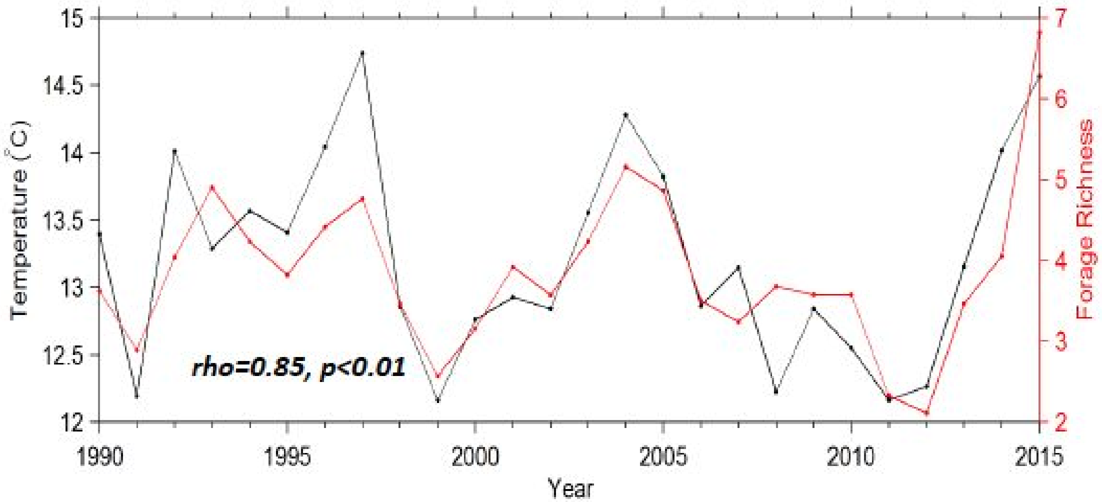
Sub-tropical and southern forage species diversity anomalies



Species richness of southern and sub-tropical forage species observed off central California is related to Sea-surface temperature anomalies (and the Pacific Decadal Oscillation).

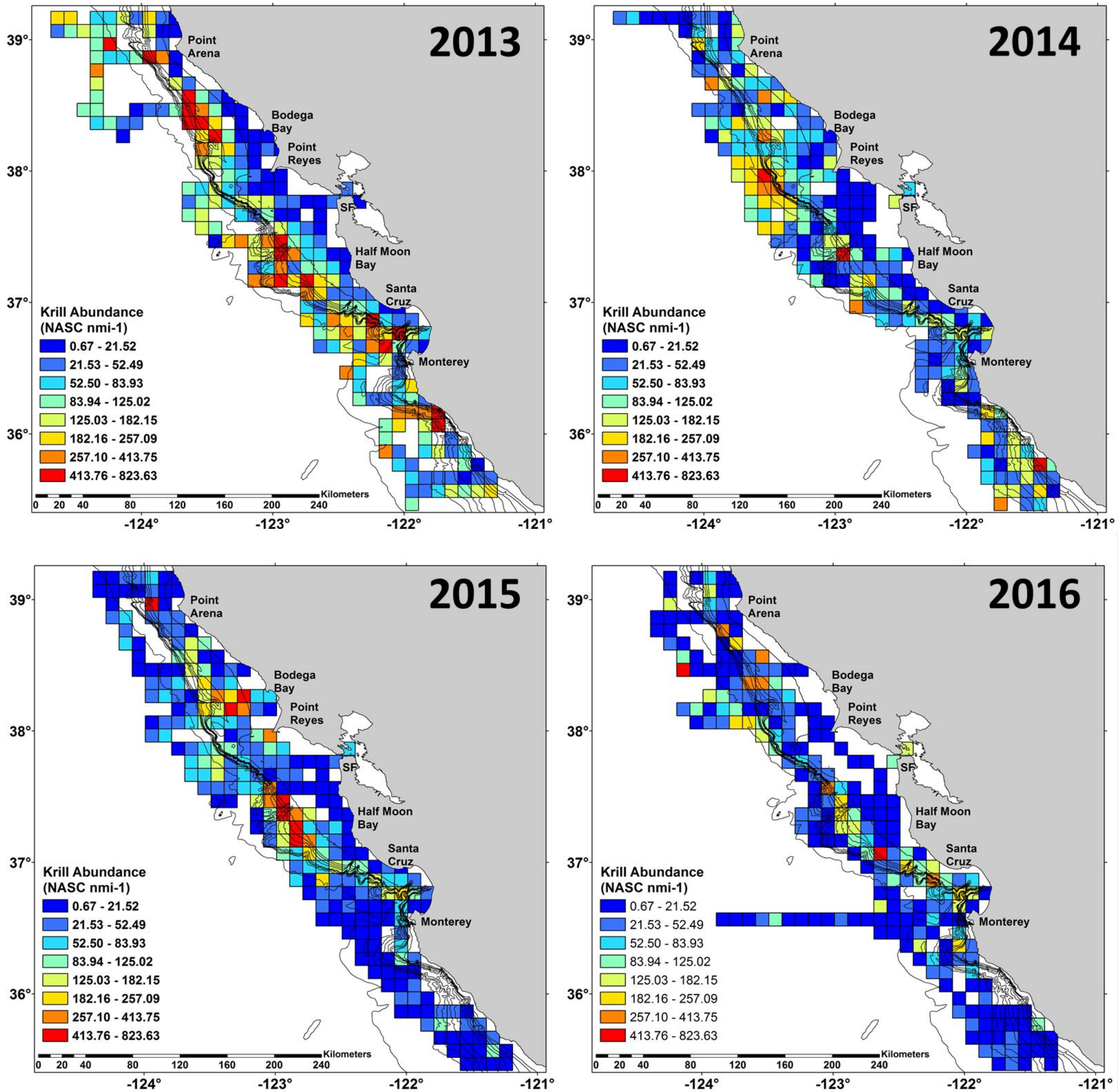
The highest species richness anomalies ever recorded occurred during 2015 (2016 was similar).





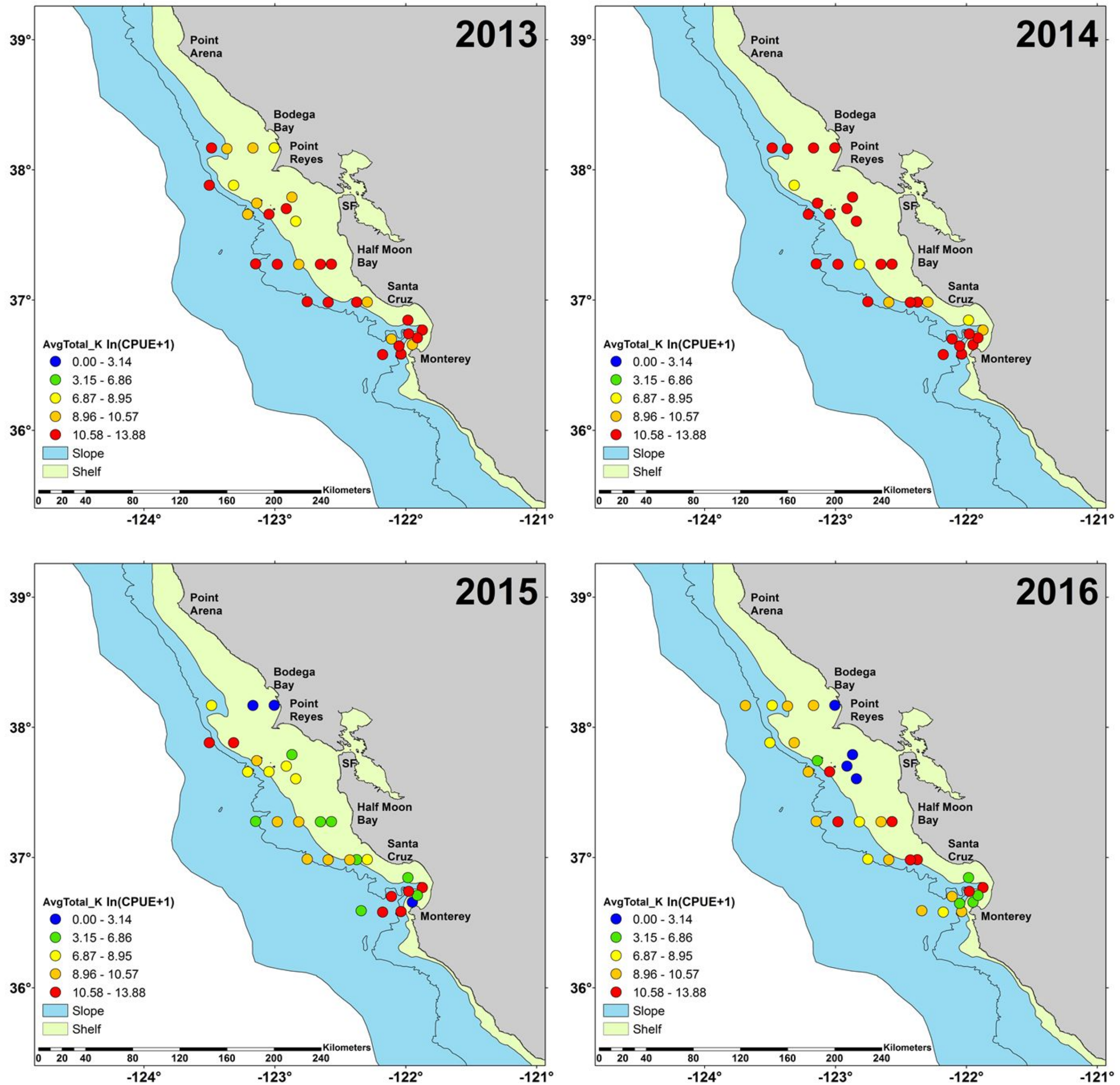
Acoustics Krill distribution & abundance (May-June; 2013-2016):

Recent acoustic observations indicate declines in abundance and spatial intensity



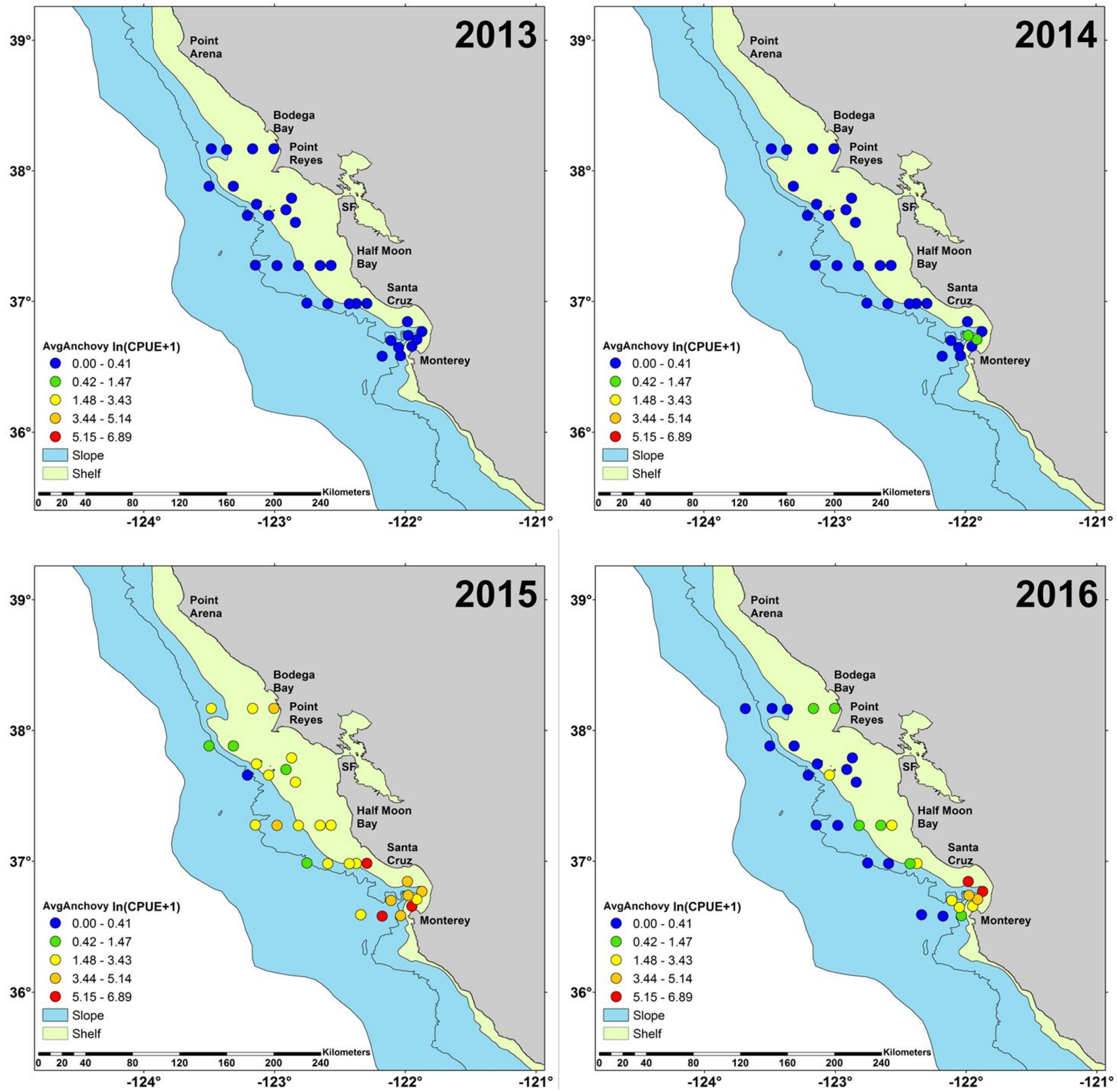
Net-hauls
Krill distribution & abundance (CPUE, May-June; 2013-2016):

Recent acoustic observations indicate declines in abundance and spatial intensity



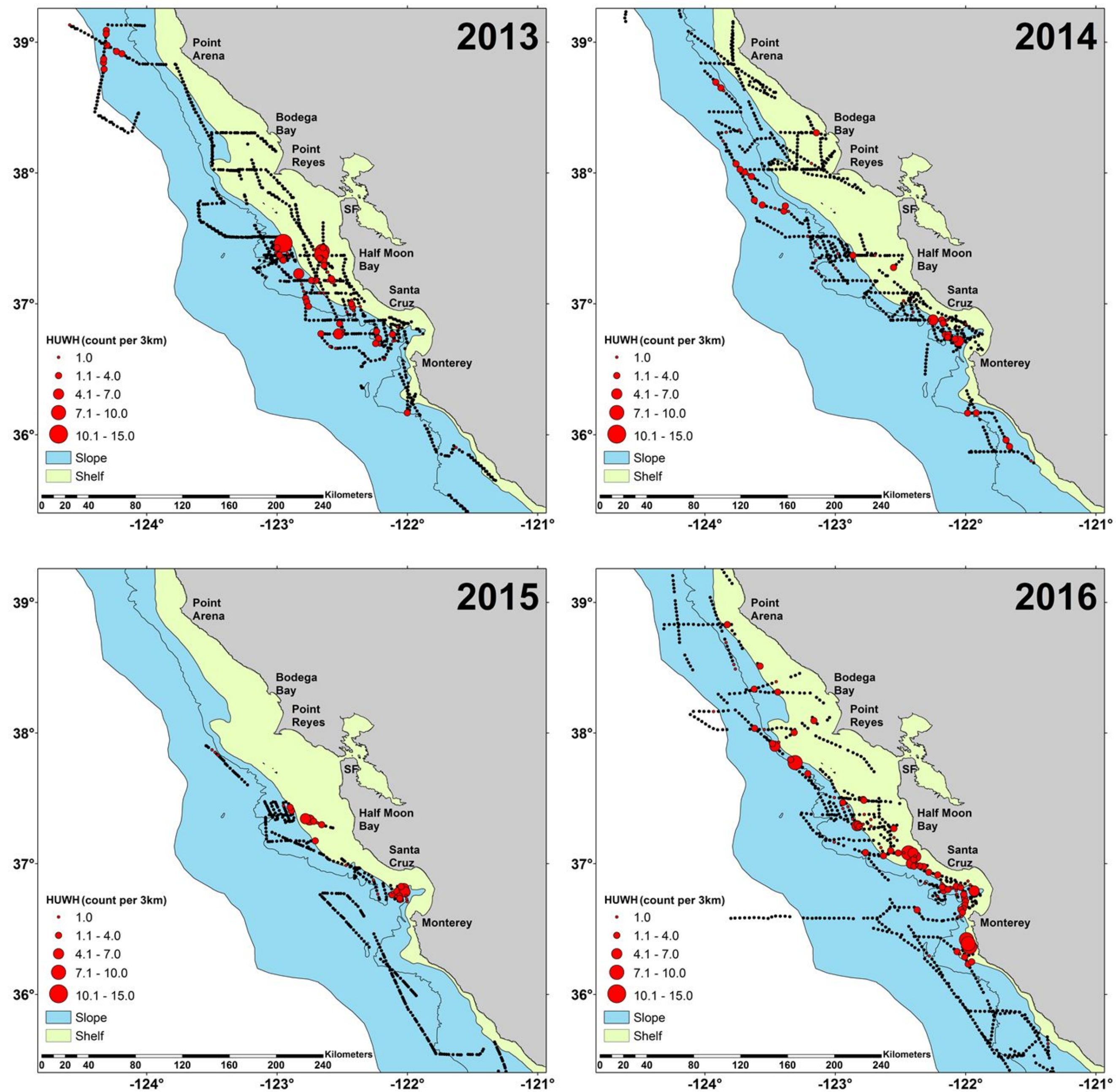
Net-hauls Anchovy distribution & abundance (CPUE, May-June; 2013-2016):

Recent observations indicate increases in abundance and spatial intensity



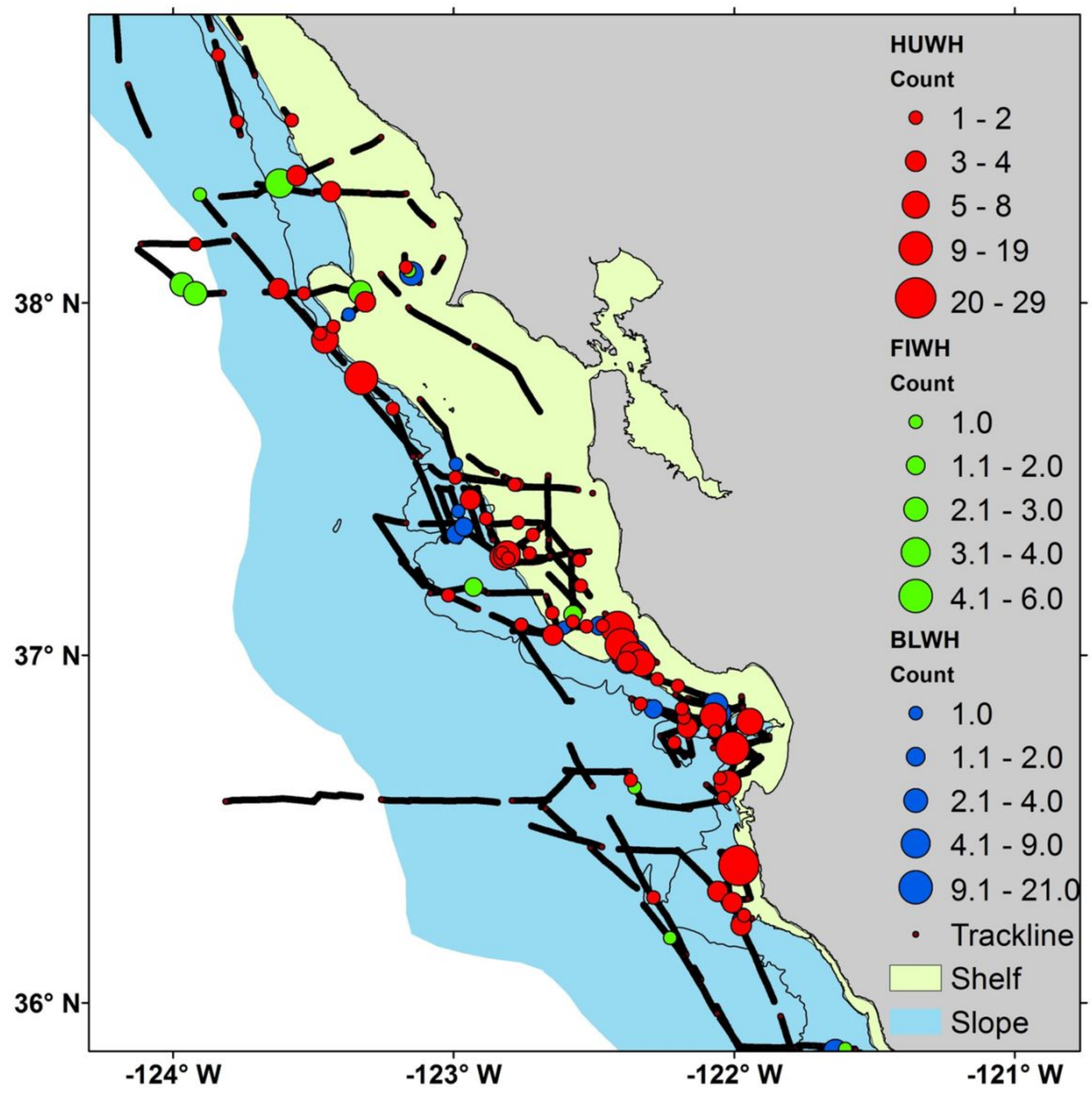
Humpback whale sightings (#/3km, May-June; 2013-2016):

Recent observations indicate increases in sightings and distribution shifts



Note: must consider whale sighting data from other surveys (incomplete)

Baleen whale sightings May-June 2016 Rockfish Recruitment and Ecosystem Assessment Survey



Summary

- Record upwelling in 2013 followed by anomalous warm sea surface temperature trend
  - different compared to previous El Niño's.
  - Influence of "the Blob"
- Krill abundance was high and hotspots were widely distributed during 2013
  - Followed by a decline in abundance and reduction in patchiness (e.g., fewer available patches in the outer shelf-break region) during 2015-2016.
- Unprecedented high diversity of forage species during large marine heatwave event of 2015; results in lower energy/lower abundant food web
- Increases in anchovy abundance, with high concentrations on the shelf; 2015-2016

Summary

- Forage perspective on conditions leading to greater or fewer chances of whale entanglements
  - Krill abundance hotspots are concentrated on the outer shelf/break slope region; especially near the edges and heads of submarine canyon systems.
  - Increase in krill abundance, results in more krill patches, and may attract more whales (especially if prey is less available to the north/south); patches should be more evenly distributed, but known hotspots should be targeted by whales.
  - Decrease krill abundance, results in fewer krill patches, may cause whales to concentrate in fewer available foraging areas.
  - During low krill years, predators that prey-switch, (e.g., humpback whales), may concentrate on alternative prey resources such as anchovy schools that typically concentrate nearshore.

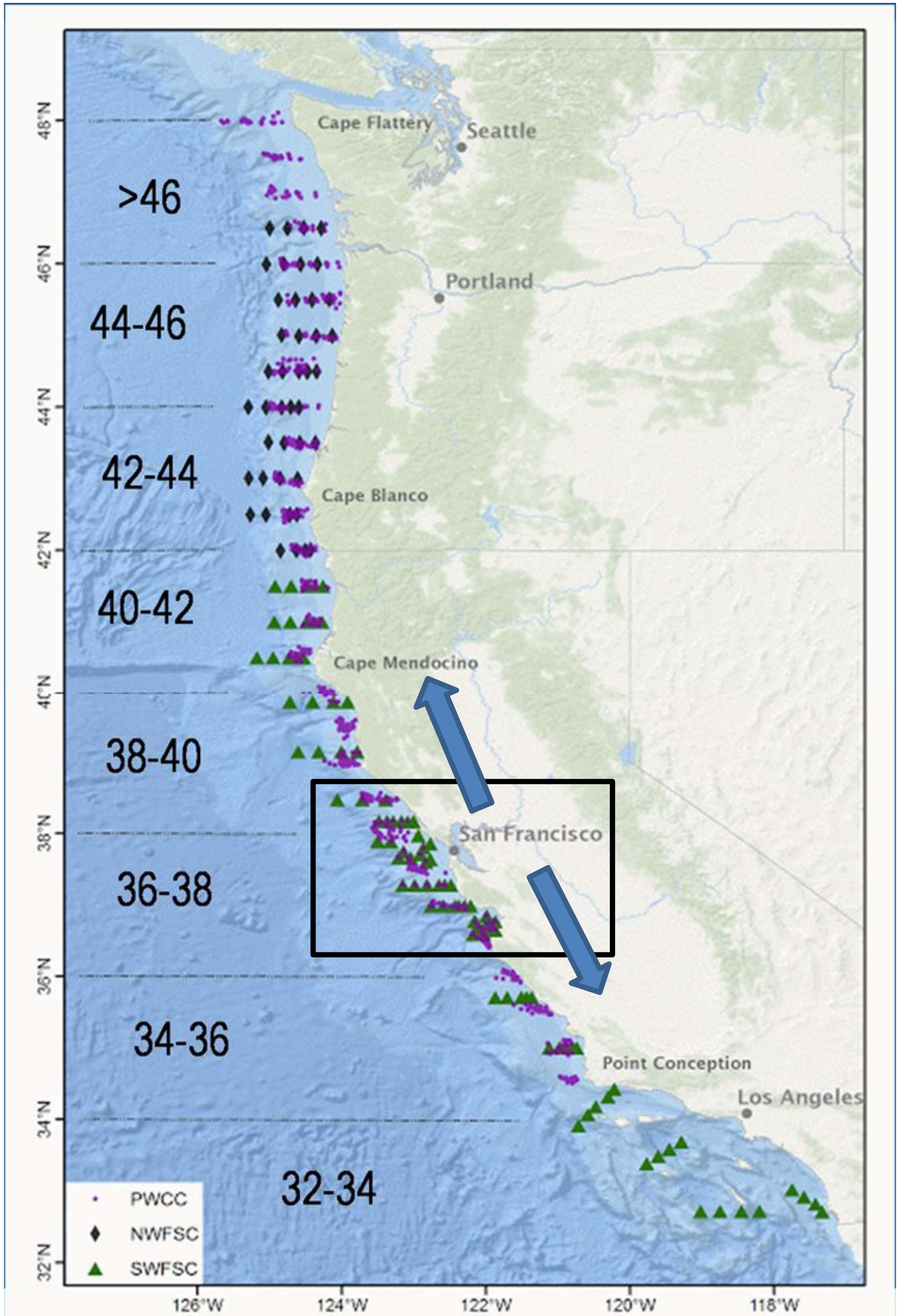
Recommendations and future considerations

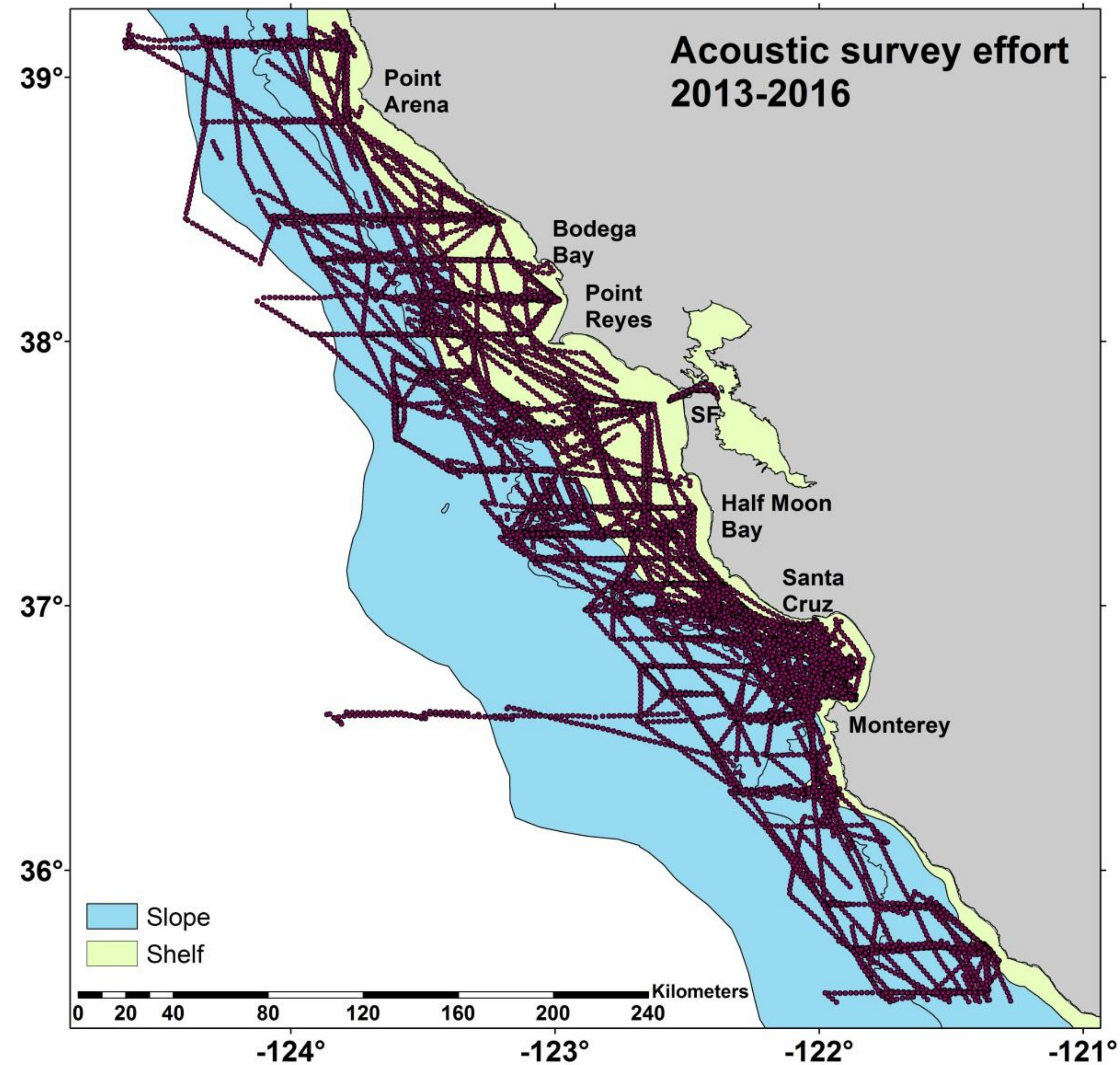
- Monitor krill hotspots and anchovy occurrence patterns
  - Coordinate observations of krill and anchovy with fishing community
- Evaluate and integrate forage species distributions in whale habitat models.
- Utilize satellite and physical oceanographic models to evaluate seasonal variability of forage species
  - Possible to forecast ecosystem state and numerical dominance of krill and anchovy months prior to sampling of fishing season
- Mindful that as whale populations continue to recover they will likely expand into nearshore habitats; different stocks may utilize different foraging grounds
- Increased variability of marine ecosystem conditions could be the new normal
  - 2015 & 2016 were unprecedented, but unclear if these events may occur more frequently

Potential next steps

Develop similar forage species indices for northern and southern California Current to improve whale habitat models

Develop suite of forecast indicators for predicting changes in forage availability that may trigger redistribution and concentration patterns of whales





Acoustic survey effort
2013-2016
Point
Arena
Bodega
Bay
Point
Reyes
SF
Half Moon
Bay
Santa
Cruz
Monterey
39°
38°
37°
36°
-124°
-123°
-122°
-121°
Slope
Shelf
Kilometers
0
20
40
80
120
160
200
240